# home-scale photovoltaic solar applications

Since the original 1981 edition of *A Solar Design Manual for Alaska* a great deal of progress and experience has been gained using photovoltaic electric systems in Alaska. This is particularly true of off-grid, small, family-sized systems. Until now, we have not included information on how this might be done well. It is long overdue.

We have obtained from Mr. Scott Russell a very well done article from *Home Power Magazine* (www.homepower.com), one of the finest magazines of its kind in the world and dedicated to off-grid power development. The cost factor is still enormous. The first thing we will do is include a costing of a system from our newsletter, *Alaska Building Science News*, from 2001 where we analyze the use of photovoltaics as a system applied to an entire off-grid cabin-sized dwelling and analyze the cost over a period of 25 years, which is now the long-term expected performance warranty of photovoltaic cells. In that period of time however, the biggest expense becomes the replacement of batteries, which is anticipated to be necessary every six or seven years. So in the 25-year life cycle cost we assume four battery replacements, which again you will see is a very large element of the cost of photovoltaic systems.

### Comparison of Photovoltaic Power Cost with Other Renewables

(adapted from *Alaska Building Science News,* Vol. 6, No. 3, Spring 2001)

Let's look at some cost comparisons and compare various power system values for photovoltaic solar and wind systems. The comparison includes a separate item on battery costs for these systems.

Some of this information is taken from a presentation by Jito Coleman of Northern Power Systems, which was presented on September 18, 2000 at the "Photovoltaics in Alaska" all-day workshop (in Anchorage) sponsored by Sandia Laboratories, the Alaska Million Solar Roofs Coalition, and Alaska Power Authority. Additional information was gleaned from the *Backwoods Solar Electric Systems Catalog* for the year 2000. This reference contains several commercially available packages which provide case studies for costs, albeit costs for a company from Sand Point, Idaho.

The photovoltaic cost discussion:

Since the capital costs are a very large part of any photovoltaic system, and operation and maintenance are less, we need to know what the energy production is and divide that energy production by the total capital cost. This calculation gives an idea of what the present cost per kilowatt-hour is of photovoltaic power. For energy production, we assume that the sun is available five hours per day on an annual average and it's available for 270 days a year (rather than 360 days for more southerly locales.) For a 20-year estimated life (this is a very conservative underestimate as most PV systems will probably last longer than this in a northern climate at the typically lower low mean annual temperatures, in which they work better than at higher temperatures), the result is approximately 1,350 watt-hours per PV installed watt per year. For 20 years then you can expect approximately 27-kilowatt hours to be produced from each installed photovoltaic watt. Taking the $8 per peak watt total cost and dividing by 27 kWh indicates that the total cost per kWh then is 29.6 cents. Running the same calculation with $9 per peak watt costs yields a cost per kWh of 33.3 cents.

Mr. Coleman, in his presentation, pointed out that solar "may be" contributing approximately 10¢ per kWh in environmental credits. This is a very important consideration. Wind has some of these credits to offer as well. By these environmental credits, we mean that there is a great deal to be gained by utilizing photovoltaic power and any renewable source of power, because of the environmental damages that are *not* generated by using renewables, such as the mining of coal, the burning of coal, the emissions of fuel exhaust.

To add a greater dimension of realism and complexity to the comparison, we go to the market as it exists in the case study examples for independent power systems in the *Backwoods Solar Electric Catalog*. These are calculations using 2002 dollars.

A good starting example is their "Case 2 system" described as a Conserving Small Home system, as follows:

A modest power system which runs high efficiency lighting, TV, stereo, and DC water pumping, plus the AC power inverter runs color TV, VCR or satellite receiver, stereo, vacuum, sewing machine, hand-held power tools, computer, blender, etc. An AC generator is used for large appliances, like clothes washer, deep well pump, or a table saw, and charges the battery at the same time. The battery is usually a 12-volt.

SOLAR PANELS 300-450 Watts, plus mounts . . . . . . . . . . . . . . . . $1,837-2,782
CHARGE CONTROL: RV30-S, or C40 . . . . . . . . . . . . . . . . . . . $175-250*
METERS: TriMetric Battery Meter . . . . . . . . . . . . . . . . . . . . . . . . $185
HARDWARE, main fuses and connecting wires as needed . . . . . . . . . . . . . . . $100
*(try Solpan-30 power center instead of the three lines above. @ . . . . . . $690-835
A Solpan power center is much easier for a do-it-yourselfer. It is "plug and play," the wire sizes and fuse sizes are done for you. No bush engineering required.)

BATTERIES: 4 to 8 Trojan T-105, cables, etc. . . . . . . . . . . . . . . . . . . $316-640
Upgrade to 2 to 4 Trojan L-16s, cables, etc. . . . . . . . . . . . . . . . . . $500-1,000

INVERTER/CHARGER: Trace UX inverter/charger, or separates such as ProSine 1000 or Powerstar inverter, plus Truecharge charger . . . . . . . . $600-1,020

System cost range: $3213-5277 (assumes selection of Solpan-30 option). Using the Solpan and the larger, better L-16 batts, the cost is $3,627-5,637. These costs do not include installation costs, and battery costs should be multiplied by four, assuming replaced four times in 25 years. The L-16s need to be replaced every 6.25 years thereafter, until the system is 25 years old. (L-16 batteries are expected to last 5-7 years with proper care.)

Since we want to get a good estimate of the cost per kwh for a 25-year system, we add to the system cost range above the range of costs for three replacements of the batteries over the assumed 25-year life. This is a range between $1500 for the 2 L-16s to $3000 for 4 L-16s.

The full system cost range for 25 years then becomes: $5,127-$8,627 using the L-16 battery options.

This range is for a system which has 300 watts for the lower, and 450 watts for the higher cost. Dividing each of these peak watt values by the respective system cost, we get the cost over 25 years per peak watt.

For the 300-watt system, this is $17.09 per peak watt, and for the 450-watt system, it is $19.17.

Combining the previous calculations for the cost per peak watt and the production of total kilowatt-hours per peak watt for the 25-year projected life of the system, we can determine the cost per kwh for an Alaska example system:

$17.09/33.75 kwh per peak watt
= $.506 per kwh
$19.17/33.75 kwh per peak watt
= $.568 per kwh

The cost is slightly cheaper per kwh, with a longer lifespan system (25 years), because fewer batteries yields less battery maintenance, less connector cables, less hydro-caps needed. It is also a safer, quicker, easier, and a more professional installation using the Solpan panel. (This last information is credited to Greg Egan.)

Here are a series of tables indicating what one might expect as an economic payback for wind generators. To determine energy costs, we divide the ranges of wind generators into common size classes: 10 kilowatts, 100 kw, and 1,000 kw. The cost for the wind tower and turbine for a 10 kw system is $23,500, for 100 kw it's about $140,000, and the megawatt (1000 kw) system is about $850,000. For the erection and the balance of the system (BOS) costs, it's only $5,000 for the 10 kw machine, about 30,000 for 100 kw, and $150,000 for a megawatt machine. The totals then sum on the third line (Table 2) to $28,500 for 10 kw, $170,000 for 100 kw and a $1,000,000 for a megawatt. By simply working backwards then, on a peak output basis, the dollars per kilowatt then become $2,850 for 10 kw wind system, $1,700 for 100 kw and about $1,000/kw for a one megawatt system. Interestingly that last number is about as cheap as any new power system (that is not diesel) presently available. That competes with gas turbines, and certainly is much cheaper than coal or large diesel-fired turbines.

There are small wind generators which early adopters and residential off-grid customers may use, which we don't want to ignore in this evaluative comparison. These small generators typically produce 300 to 1500 watts, and cost between $500 and $2000, plus a vast range of installation costs which are difficult to estimate do to the strategic and individual nature of siting a wind turbine. An additional set of unknowns is the maintenance and expected life of these units.

Of course the amount of energy and the cost of energy you get from a wind system depends greatly on the annual wind speeds. Table 3 shows, at variable wind speeds from 10 to 18 mph what the cost per kwh is for each of the three system sizes.

**Table 2.** Wind Energy Costs for three size increments

| | SYSTEM PEAK SIZE | | |
|---|---|---|---|
| | 10 kw | 100 kw | 1000 kww |
| Wind turbine & tower | $23,500 | $140,000 | $ 850,000 |
| Erection and BOS | $ 5,000 | $ 30,000 | $ 150,000 |
| TOTAL | $28,500 | $170,000 | $1,000,000 |
| $/kw | $ 2,850 | $ 1,700 | $ 1,000 |

**Table 3.**
Annual Wind Speed vs. kWh cost

| | 10 kw | 100 kw | 1000 kw |
|---|---|---|---|
| 10 mph | 27.7¢ | 16.3¢ | 9.0¢ |
| 12 mph | 23.4¢ | 13.8¢ | 7.5¢ |
| 14 mph | 19.8¢ | 11.6¢ | 6.3¢ |
| 16 mph | 16.3¢ | 9.5¢ | 5.0¢ |
| 18 mph | 13.4¢ | 7.8¢ | 4.0¢ |

**Diesel Generators**

Next we look at the actual costs for a reciprocating diesel engine genset. The genset cost is only $350 - $600/kw and the installation and balance of system is typically $50 - $200/kw additional. The energy conversion of a diesel reciprocating engine is anywhere from 10 to 16 kw per gallon of fuel purchased. The delivered fuel cost in Alaska can range anywhere from 80¢ per gallon to as much as $6 per gallon. This is particularly the case, (the high end, that is) in areas where it's difficult to get a barge or an aircraft of considerable size to a small village. The operation and maintenance are also significant, coming in at about 2¢ to 4¢ a kwh for a diesel system.

**Table 4.** Reciprocating Engine Costs (Diesel gensets)

| | | |
|---|---|---|
| Genset Cost | $350 - $600/kw | |
| Install and BOS | $ 50 - $200/kw | |
| Energy Conversion | 10-16 kwh/gal | |
| Delivered Fuel | $0.80 - $6.00/gal | |
| O and M | $0.02 - $0.04 kwh | |
| | ¢ / kwh | |
| | low | high |
| O and M | 2 | 4 |
| Capital cost | 2 | 4 |
| Fuel | 5 | 60 |
| Externalities | ? | ? |

*Hugely* Fuel Cost dependent!! 9¢/kwh - 68¢/kwh

For a diesel the chart above gives some sense of per kilowatt-hour cost for various aspects of operating diesel systems. The operation and maintenance (O and M) can be anywhere from 2¢ to 4¢ a kwh. The capital cost is also about 2¢ to 4¢ a kwh. The fuel costs can be from a low of 5¢ a kwh to a high of about 60¢ a kwh. So the range is hugely dependent on fuel cost and can be from 9¢ a kwh, competitive with on-grid power in Alaska, to as much as 68¢ a kwh. You'll notice in the chart above, though, that externalities are all questionable. The diesels are noisy, they are high maintenance, they must be replaced about every five years or 10,000 hours and of course, the cost of fuel is a variable, which is out of the control of the local community.

In addition to this, there are problems with storing and handling the fuel. One of the items noted at the workshop on PV in September of 2000 in Anchorage was that 70 percent of the fuel handling facilities on the coast of Alaska are now condemned by the U.S. Coast Guard. And they will stay that way because there is no money to fix them, and no program presently available to make them come up to the specification that would make them acceptable for safe handling of fuels.

**Table 5**. Power System Values

| | Renewable | Fossil Fuel |
|---|---|---|
| Energy Reliability | very high as hybrid | very high with back-up |
| Energy Security | very high as hybrid | as high as OM and fuel delivery reliability |
| Price | can sometimes be lowest | low to high based upon fuel delivery |
| Price Security | very secure - most costs upfront | low: unknown future fuel cost & environmental |
| Environment Values | very high | medium to low |

As an overall review of various values in comparing renewable versus fossil fuel energy and power systems, Table 5 compares renewables and fossil fueled power systems.

## Solar-Electric Systems Simplified

by Scott Russell

Perhaps what the home-scale renewable energy (RE) world needs most are ways to introduce people to RE technologies and the gizmos that make it possible. After all, even the best ideas aren't embraced until they are explained in simple terms.

So whether *you* are the rookie who wants to understand how solar-electric systems work, or that better describes your spouse, friend, or prospective customer, this article explains the guts and bolts of the three most common options in solar-electric systems: grid-intertied, grid-intertied with battery backup, and off-grid (stand-alone).

Understanding the basic components of an RE system and how they function is not an overwhelming task. Here are some brief descriptions of the common equipment used in grid-intertied and off-grid solar-electric systems. Systems vary—not all equipment is necessary for every system type.

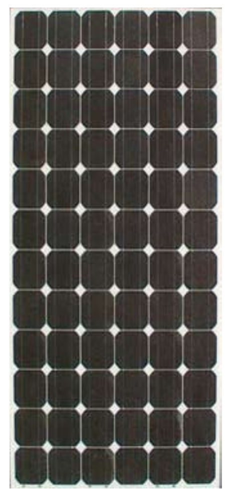
**Grid-Intertied Solar-Electric System**

Also known as on-grid, grid-tied, or utility-interactive (UI), grid-intertied solar-electric systems generate solar electricity and route it to the electric utility grid, offsetting a home's or business's electrical consumption and, in some instances, even turning the electric meter backwards. Living with a grid-connected solar-electric system is no different than living with grid power, except that some or all of the electricity you use comes from the sun.

In many states, the utility credits a homeowner's account for excess solar electricity produced. This amount can then be applied to other months when the system produces less or in months when electrical consumption is greater. This arrangement is called net metering or net billing. The specific terms of net metering laws and regulations vary from state to state and utility to utility. Alaska has no net metering or other tariff law in place as of 2005.

*Solar-Electric Panels*
*AKA: solar-electric modules, photovoltaic (PV) panels*

PV panels are a solar-electric system's defining component, where sunlight is used to make direct current (DC) electricity. Behind a PV panel's shimmering facade, wafers of semiconductor material work their magic, using light (photons) to generate electricity— what's known as the *photovoltaic effect*. Other components in your system enable the electricity from your solar-electric panels to safely power your electric loads like lights, computers, and refrigerators.



PV panels are assigned a rating in watts based on the maximum power they can produce under ideal sun and temperature conditions. You can use the rated output to help determine how many panels you'll need to meet your electrical needs. Multiple modules combined together are called an array.

Although rigid panels are the most common form of solar electricity collector, PV technology also has been integrated into roofing shingles and tiles, and even peel-and-stick laminates (for metal standing-seam roofs).

PV modules are very durable and long-lasting— most carry 25-year warranties. They can withstand severe weather, including extreme heat, cold, and hailstones.

*Array Mounting Rack*
*AKA: Amounts, racks*

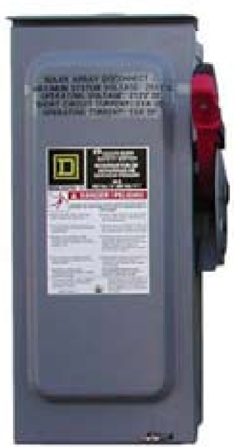
Mounting racks provide a secure platform on which to anchor your PV panels, keeping them fixed in place and oriented correctly. Panels can be mounted using one of three approaches: 1) on a rooftop; 2) atop a steel pole set in concrete; or 3) at ground level. The specific pieces, parts, and materials of your mounting device will vary considerably depending on which mounting method you choose.

Usually, arrays in urban or suburban areas are mounted on a home's south-facing roof, parallel to the roof's slope. This approach is sometimes considered most aesthetically pleasing, and may be required by local regulators or homeowner's associations. In areas with a lot of space, pole- or ground-mounted arrays are another choice.

Mounting racks may incorporate other features, such as seasonal adjustability. The sun is higher in the sky during the summer and lower in the winter. Adjustable mounting racks enable you to set the angle of your PV panels seasonally, keeping them aimed more directly at the sun. Adjusting the tilt angle increases the system's annual energy production by a few percent. The tilt of roof-mounted arrays is rarely changed— adjusting the angle is inconvenient and sometimes dangerous, due to the array's location.

Changing the tilt angle of pole- or ground-mounted arrays can be done quickly and safely. Pole-mounted PV arrays also can incorporate tracking devices that allow the array to automatically follow the sun across the sky from east to west each day. Tracked PV arrays can increase the system's daily energy output by 25 to 40 percent.

*Array DC Disconnect*
*AKA: PV disconnect*

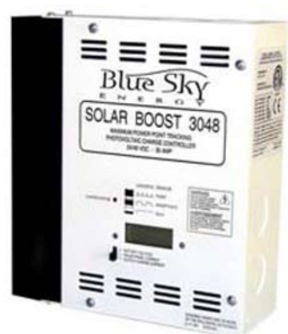


The DC disconnect is used to safely interrupt the flow of electricity from the PV array. It's an essential component when system maintenance or troubleshooting is required. The disconnect enclosure houses an electrical switch rated for use in DC circuits. It also may integrate either circuit breakers or fuses, if needed.

*Charge Controller*
*AKA: controller, regulator*

A charge controller's primary function is to protect your battery bank from overcharging. It does this by monitoring the battery bank—when the bank is fully charged, the controller interrupts the flow of electricity from the PV panels. Batteries are expensive and pretty particular about how they like to be treated. To maximize their life span, you'll definitely want to avoid overcharging or undercharging them.

Most modern charge controllers incorporate maximum power point tracking (MPPT), which optimizes the PV array's output, increasing the energy it produces. Some battery-based charge controllers also include a low-voltage disconnect that prevents over discharging, which can permanently damage the battery bank.



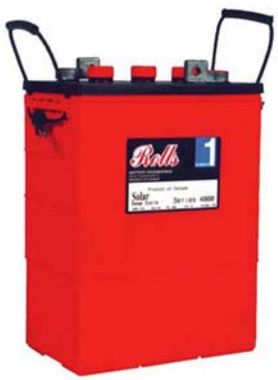

## Grid-Intertied Solar-Electric System with Battery Backup

Without a battery bank or generator backup for your grid-intertied system, when a blackout occurs, your household will be in the dark, too. To keep some or all of your electric needs (or "loads") like lights, a refrigerator, a well pump, or computer running even when utility power outages occur, many homeowners choose to install a grid intertied system with battery backup. Incorporating batteries into the system requires more components, is more expensive, and lowers the system's overall efficiency. But for many homeowners who regularly experience utility outages or have critical electrical loads, having a backup energy source is priceless.

*Battery Bank*
*AKA: storage battery*

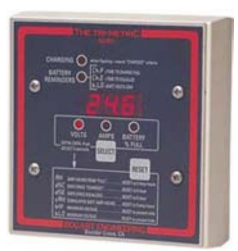
Your PV panels will produce electricity whenever the sun shines on them. If your system is off-grid, you'll need a battery bank—a group of batteries wired together—to store energy so you can have electricity at night or on cloudy days. For off-grid systems, battery banks are typically sized to keep household electricity running for one to three cloudy days. Grid-intertied systems also can include battery banks to provide emergency backup power during blackouts—perfect for keeping critical electric loads operating until grid power is restored.

Although similar to ordinary car batteries, the batteries used in solar-electric systems are specialized for the type of charging and discharging they'll need to endure. Lead-acid batteries are the most common battery used in solar-electric systems. Flooded lead-acid batteries are usually the least expensive, but require adding distilled water occasionally to replenish water lost during the normal charging process. Sealed absorbent glass mat (AGM) batteries are maintenance free and designed for grid-tied systems where the batteries are typically kept at a full state of charge. Gel-cell batteries can be a good choice to use in unheated spaces due to their freeze-resistant qualities.



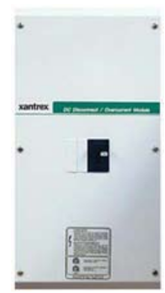

*System Meter*
*AKA: battery monitor, amp-hour meter*

System meters measure and display several different aspects of your solar-electric system's performance and status, tracking how full your battery bank is; how much electricity your solar panels are producing or have produced; and how much electricity is in use. Operating your solar-electric system without metering is like running your car without any gauges—although possible to do, it's always better to know how much fuel is in the tank.



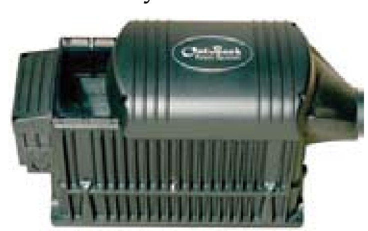
*Main DC Disconnect*
*AKA: battery/inverter disconnect*

In battery-based systems, a disconnect between the batteries and inverter is required. This disconnect is typically a large, DC-rated breaker mounted in a sheet-metal enclosure. This breaker allows the inverter to be quickly disconnected from the batteries for service, and protects the inverter-to-battery wiring against electrical fires.




*Inverter*

Inverters transform the DC electricity produced by your PV modules into the alternating current (AC) electricity commonly used in most homes for powering lights, appliances, and other gadgets. Grid-tied inverters synchronize the electricity they produce with the grid's "utility-grade" AC electricity, allowing the system to feed solar-made electricity to the utility grid.



Most grid-tie inverters are designed to operate without batteries, but battery-based models also are available. Battery-based inverters for off-grid or grid-tie use often include a battery charger, which is capable of charging a battery bank from either the grid or a backup generator during cloudy weather.

Most grid-intertie inverters can be installed outdoors (ideally, in the shade). Most off-grid inverters are not weatherproof and should be mounted indoors, close to the battery bank.

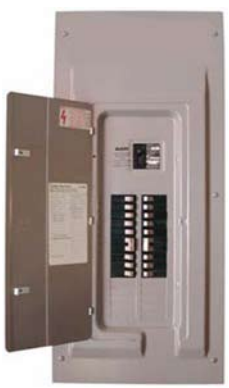

**Off-Grid Solar-Electric Systems**

Although they are most common in remote locations without utility grid service, off-grid solar-electric systems can work anywhere. These systems operate independently from the grid to provide all of a household's electricity. That means no electric bills and no blackouts—at least none caused by grid failures.

People choose to live off-grid for a variety of reasons, including the prohibitive cost of bringing utility lines to remote homesites, the appeal of an independent lifestyle, or the general reliability a solar-electric system provides. Those who choose to live off-grid often need to make adjustments to when and how they use electricity, so they can live within the limitations of the system's design. This doesn't necessarily imply doing without, but rather is a shift to a more conscientious use of electricity.

*AC Breaker Panel & Inverter AC Disconnect*
*AKA: mains panel, breaker box, fuse box*

The AC breaker panel is the point at which all of a home's electrical wiring meets with the "provider" of the electricity, whether that's the grid or a solar-electric system. This wall-mounted panel or box is usually installed in a utility room, basement, garage, or on the exterior of the building. It contains a number of labeled circuit breakers that route electricity to the various rooms throughout a house. These breakers allow electricity to be disconnected for servicing, and also protect the building's wiring against electrical fires.



Just like the electrical circuits in your home or office, an inverter's electrical output needs to be routed through an AC circuit breaker. This breaker is usually mounted inside the building's mains panel, which enables the inverter to be disconnected from either the grid or from electrical loads if servicing is necessary, and also safeguards the circuit's electrical wiring.

Additionally, utilities usually require an AC disconnect between the inverter and the grid that is for their use. These are usually located near the utility KWH meter.

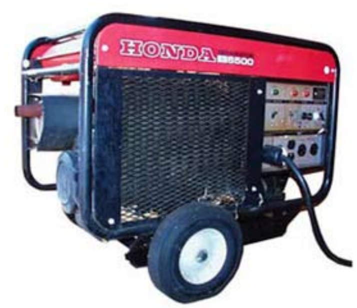
*Kilowatt-Hour Meter*
*AKA: KWH meter, utility meter*

Most homes with a grid-tied solar-electric system will have AC electricity both coming from and going to the electric utility grid. A bidirectional KWH meter can simultaneously keep track of how much electricity flows in each of the two directions—just the information you need to monitor how much electricity you're using *and* how much your solar-electric system is producing. The utility company often provides intertie-capable meters at no cost.

*Backup Generator*
*AKA: gas guzzler*

Off-grid solar-electric systems can be sized to provide electricity during cloudy periods when the sun doesn't shine. But sizing a system to cover a worst-case scenario, like several cloudy weeks during the winter, can result in a very large, expensive system that will rarely get used to its capacity. To spare your pocketbook, size the system moderately, but include a backup generator to get through those occasional sunless stretches.

Engine generators can be fueled with biodiesel, petroleum diesel, gasoline, or propane, depending on the design. These generators produce AC electricity that a battery charger (either standalone or incorporated into an inverter) converts to DC energy, which is stored in batteries. Like most internal combustion engines, generators tend to be loud and stinky, but a well-designed solar-electric system will require running them only 50 to 200 hours a year.



**Solar-Electric Systems Demystified**

As you can see, the anatomy of a photovoltaic system isn't that complicated. All of the parts have a purpose, and once you understand the individual tasks that each part performs, the whole thing makes a bit more sense. Now you're ready to look at the system articles and schematics in *Home Power* without your eyes glazing over, and you'll have a clearer understanding of what is going on in the articles.

To solidify your understanding, your next task should be to examine a solar-electric system in person. The National Tour of Solar Homes each fall is one way to see a variety of systems. Also, many renewable energy fairs and workshops feature tours of solar homes. Check the listings for your area in the *Happenings* calendar in each *Home Power* issue to find out where you can learn more about RE systems and meet the people who are using renewable energy in your area.

*ACCESS*

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